Title: Locomotives

Creators: Lynch, Roland H.

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LOCOMOTIVES

By Roland H. Lynch

THE activities of mankind have brought many forms of transportation—forms which have come and gone and forms which have remained. Railroads have long occupied a key position in the transportation system of this country and, despite the increasing competition of other varieties of transportation, railroads will continue to advance, for any system so fundamental to the commercial progress of the country cannot be easily displaced. Recent developments of Diesel and electric locomotives have brought increased emphasis upon this phase of locomotive design but experts say that the steam locomotive will continue to do the major portion of the railroads' work. For this reason it seems imperative that a few of the leading facts about steam locomotives should form a part of every engineer's background.

The Whyte system of classifying locomotives is used almost universally at the present time. In this system the numeral designation is based on wheel arrangement, for example, there is the 4-8-4 type, in which the first numeral refers to the number of wheels of the leading truck, the second numeral to the number of driving wheels, and the third to the number of wheels on the rear truck. A four-numeral designation such as 4-8-8-2, shows that the locomotive has two sets of driving wheels with 8 wheels per set.

The four main parts of a locomotive, that is if you can consider any part more essential than another, are the firebox, the boiler, the cylinders, and the driving wheels. These parts, of course, are interdependent; the size or capacity of one affecting to varying degrees the size or capacity of another. If the boiler or furnace is the smallest of the four main parts, the wheels may stop because the steam pressure falls. If the cylinder power is smaller than the other three the engine may be stalled though using full steam pressure. If the tractive force at the wheels is smallest the engine will slip the drivers.

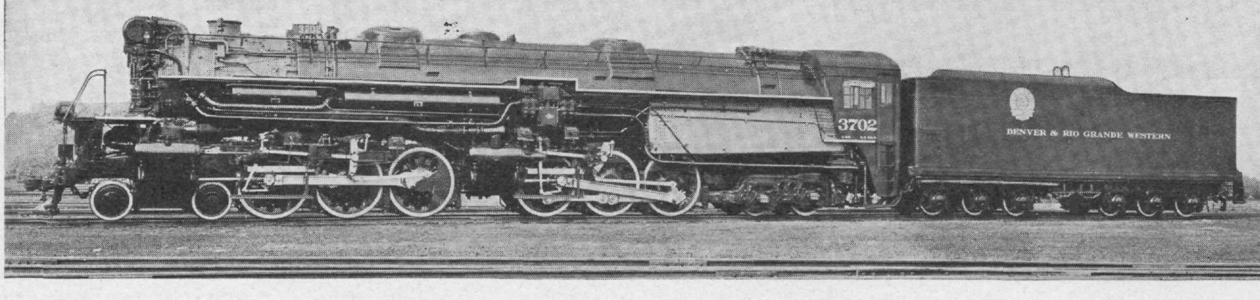
And so come the problems. With the drivers, we are concerned with the allowable tractive force without slipping; with the cylinders, we consider the work done by the steam on the piston; with the boiler such a quantity of steam must be evaporated at the desired pressure to maintain the required force at the track. The piston, acting merely to transmit the force, may be infinitely large, but, even so, not large enough to move the locomotive if the boiler cannot maintain pressure. The firebox must supply sufficient heat to evaporate all the water that is demanded by the load.

The capacity of a locomotive may be considered in terms of its starting tractive force and be expressed by the formula $F = MW$ where

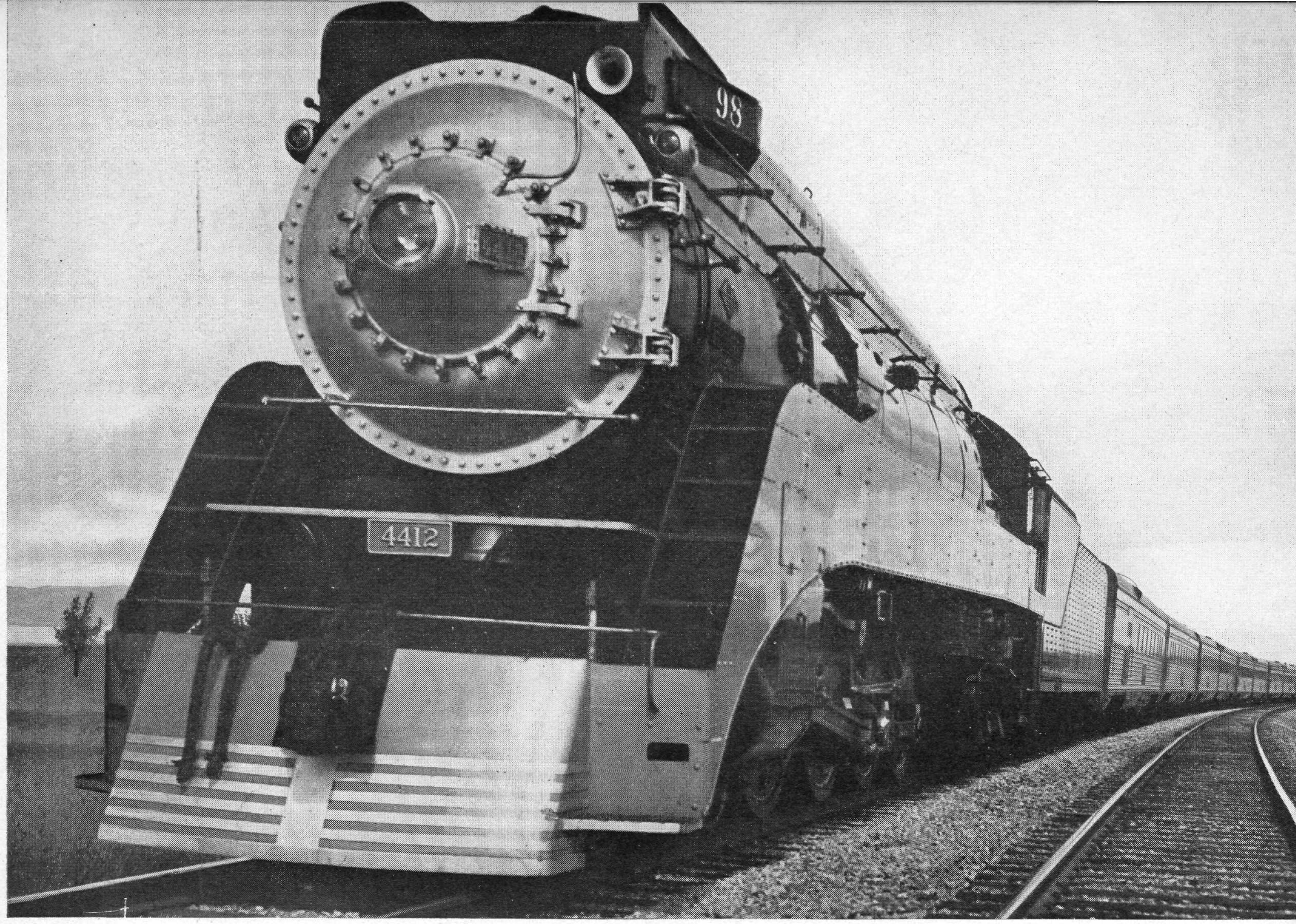
F = maximum possible tractive force
M = coefficient of friction between wheels and track, usually taken at approximately $\frac{1}{4}$
W = that part of the total weight of the locomotive which can be placed upon the driving wheels.

Hence it is seen that the weight of a locomotive directly affects its capacity. This does not mean, however, that you merely put a heavy locomotive on the rails and your job is done. Other questions such as power and fuel consumption are involved. While an increase in the weight of a locomotive increases its capacity it is obvious that such a procedure would demand more power and greater fuel consumption.

Consideration such as these force the designer to yield to certain restrictions when developing a locomotive for a particular type of work and its use in any other class than that for which it was designed would prove uneconomical. While a passenger locomotive may look like a freight locomotive to the uninitiated, they are definitely non-interchangeable. The passenger locomotive with its huge driving wheels is a high-speed machine, whereas the freight locomotive is designed to give lowest unit cost at a moderate speed.



Courtesy Baldwin Locomotive Works



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Capacity may be expressed, in addition to starting tractive force, as horsepower developed at rated speed. Capacity in this sense as well as other performance characteristics of an engine is determined to a large extent by the boiler evaporation rate and the steam consumption per horsepower hour. The cylinder steam consumption is greatest at low speeds. Hence it follows that efficiency increases with increasing speeds. The maximum efficiency occurs at or near rated speeds, making it essential for the sake of economy to operate locomotives at or as near to rated conditions as can be obtained in practice. This is particularly true at the present time when most railroads are operating under such severe financial conditions that greatest economy is a necessity.

These financial reverses are, to some extent, affecting the design of the heavy freight locomotive. Inasmuch as low operating speeds are not uncommon, efficiencies tend to be low. The money factor makes it imperative to seek means and methods of increasing efficiency. One way of getting the desired results is by the use of high pressure compound locomotives. In this method, the steam which is exhausted from the initial high pressure cylinder is used again to drive a low pressure piston. It is obvious that the second piston must have a much greater area than the first in order to compensate for the reduction in pressure. By means of this method the steam is made to do mechanical work more than once before being exhausted. This leads to greater efficiency and reduced costs as well as increasing the range of economical speeds and at the same time reducing the rate of water consumption. Another procedure is to superheat the steam. This superheating provides an increase in steam volume of about 33% for an increase of only 10% in heat along with the important fact that cylinder condensation is prevented. This superheating is accomplished by means of superheater units placed in the boiler and makes possible the surprising results of increased tonnage at higher speeds while at the same time showing a marked decrease in coal per ton-mile. And yet a third is to adjust the inlet valve to close earlier, thus converting a higher percentage of heat energy into mechanical energy. Engines which operate in this way are known as "limited cut-off" locomotives.

Along the line of efficiency one sometimes meets a term, "machine efficiency," that might deserve mentioning as it is somewhat misleading. This refers to the ratio of the tractive force actually delivered at the rails to the force which would be delivered if there were no friction losses. The machine efficiency is a maximum at starting and decreases steadily as speed builds up due to the fact that the friction losses are greater at higher speeds. A true operating efficiency involves the ratio between two power or work factors whereas this "machine efficiency" is a ratio between two forces.

Another common term in the locomotive language is **drawbar pull.** This term refers to the force exerted between the locomotive tender and the rest of the train. The drawbar pull is less than the tractive force when the train is accelerating due to the combined efforts of inertia and friction in the locomotive itself.

But we aren't through with efficiency yet by a long way if we don't say something about thermal efficiency. Thermal efficiency may be expressed as the ratio of the work done at the drivers to the energy released by the fuel. It is quite surprising to learn that the thermal efficiency of a locomotive averages about 6 per cent, a mere 6 per cent. An example will show how this comes about. Under present-day firing methods bituminous coal develops between 12,000 and 15,000 B.t.u. per pound so 13,500 B.t.u. might be taken as a mean value. One-third to one-half of this energy may be lost in the transfer of heat to the steam. This means, in round numbers, that some 8,000 B.t.u. from the original 13,500 are in the steam. Of this number, less than one-tenth, 700 for the sake of convenience, are transferred into useful work at the drivers. But $700/13{,}500 = 5\%$ and this is only the thermal efficiency. Other losses, mechanical and frictional, further reduce the total efficiency of a locomotive until a figure slightly less than the above is reached. The greatest single loss, 5000 odd B.t.u. in this example, is due to the heat that goes unceremoniously out the exhaust and up the stack.

By this time, from the factors already mentioned, you have probably reached the conclusion that locomotive design is quite complicated—and you are right. In fact complicated is putting it rather mildly. In addition to the many factors directly influencing the design, dozens of outside factors exert their influence in varying proportions. The forces, both static and dynamic, that the locomotive exerts upon the supporting roadbed or bridge, not exactly a problem for an amateur mathematician, must be calculated. These forces determine the general design that must be employed in order to provide a satisfactory margin of safety. Clearance limits determined by the sizes of bridges, signals, station platforms, tunnels and the like obviously must be considered in locomotive design—yet a structure must be developed which will produce the desired effect although hampered by these definite limitations. The location of the run, that is the gradients and curvatures encountered, sets the power and

Courtesy Lima Locomotive Works

RIGHT OR WRONG?

A 2-minute test for telephone users

1. It's impossible for you to telephone to people in two different cities at the same time.

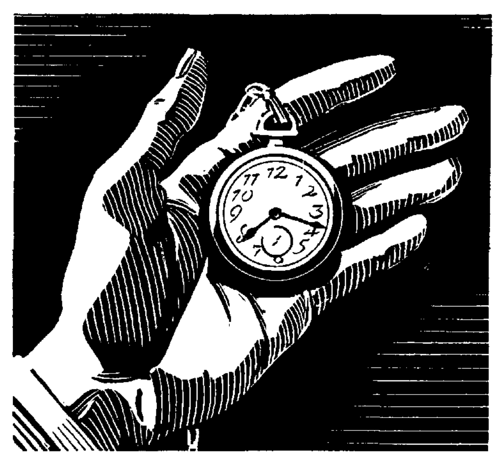
RIGHT ☐ **WRONG** ☐

2. Police Radio Telephone made by Western Electric is an outgrowth of research at Bell Telephone Laboratories.

RIGHT ☐ **WRONG** ☐

3. About 75% of the Bell System's 85 million miles of telephone wire is contained in cable.

RIGHT ☐ **WRONG** ☐



4. Lowest telephone rates to most out-of-town points are available every night after 7 P. M. and all day Sunday.

RIGHT ☐ **WRONG** ☐

ANSWERS:

1. *Wrong.* Telephone Conference Service enables you to talk simultaneously with as many as five other people.

•

2. *Right.* And that's true also of broadcasting equipment, aviation radio telephone and marine radio telephone.

•

3. *Wrong.* Over 95% is now protected by cable — nearly ⅔ of which is underground.

•

4. *Right.* Why not telephone home oftener? Your family will enjoy it—so will you!

AMERICAN TELEPHONE & TELEGRAPH CO. AND ASSOCIATED COMPANIES — BELL SYSTEM

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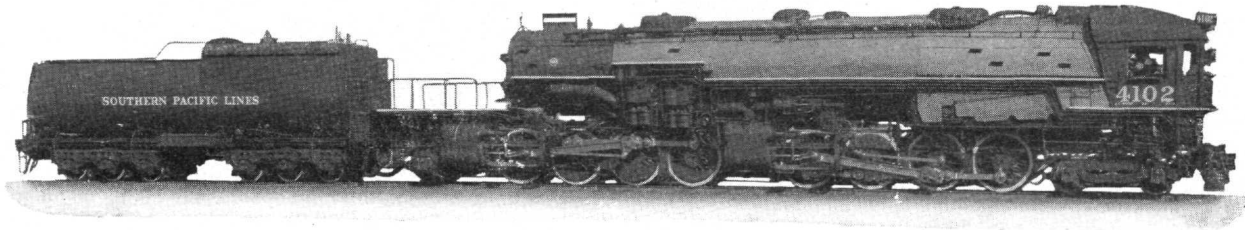
size characteristics. Speed requirements, already mentioned, vitally affect the design. The length of the run must be taken into account and the location of fuel and water supplies must not be overlooked. Such considerations enter into the design just as truly as the machine's load-carrying capacity itself.

After the questions involved in considering the operating conditions are settled, the actual design is taken up. The wheel arrangement, the first on the list, once determined, is the fuse to a blast of mathematics which involve the boiler and cylinder capacities. Still more figuring is required in determining the grate area, fire-box volume and other necessary dimensions and capacities. This goes on and on and on.

And now comes assembly with its problems. Valves, pipe lines, gears, levers and the like must be designed or selected with care if smoothness of operation is to be achieved. The frame is either cast as a single complicated piece or built up of separate smaller parts welded or otherwise fastened together. The parts are then positioned and the various attachments made. Upon the completion of exacting tests the locomotive is ready to take its place in this work-a-day world.

One last point and we'll call it a day. Mathematics alone won't make a perfect locomotive — experience, logic and empirical knowledge must be included in the design for locomotive design is not only a science but an art.



Courtesy Baldwin Locomotive Works